DIGITAL POWER SUPPLY DEVELOPMENT AT THE PLS*

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Abstract

Digital power supply controller using the Digital Signal Processor (DSP) and Field Programmable Gate Array (FPGA) has been developed over the year at the Pohang Light Source (PLS). Recently, full digital buck type bi-phase PS development completed and tested using as the PSI card. A new digital controller is designed as 3 U euro-standard sizes and provides overall performance of the power supplies stability better than ± 5 ppm short-term stability (< 1 min) and ± 25 ppm long-term stability (< 12 hours). It is made use of the digital PI current controller which has one-pole digital filter and feed-forward voltage ripple compensation control algorithms. This paper presents the hardware and software structure of the developed digital controller and experimental results of digital power supply.

INTRODUCTION

Accelerator complex power supply application were increased to choose the based on digital technology [1],[3]. At 1999, the PSI developed the new digital control cards used DSP, FPGA and high precision AD. It was very successfully implemented to beam operation [2]. At 2005, PLS has been successfully replaced over 70 vertical correction PS sets same as PSI digital type, it has good performance and reliability for orbit feedback operation. At 2006, DLS facility commissioned digital type PS for BOOSTER, LINAC and even storage ring [3]. And SSRF in China also trying to develop digital controlled PS for the BOOSTER. PLS has the working experience of the digital PS since 2005 and had satisfactory experimental results. We choose the same type of digital controller for FIR solenoid PS. It is required single quadrant, 200 A, 25 ppm stability. The main topology has a phase shifted parallel operation mode. Practically bi-phase methods are complicated to have current balancing to each lags. But digital controller is capable of the fast cross-over frequency and 20 μs control loops for single feedback loops. This paper descries the implementation of the 20 V / 200 A bi-phase buck converters used full digital controller.

POWER SUPPLY SPECIFICATION

Hardware specification

Switch-mode power supply more advantages than linear type power supply. Switch-mode a buck type PS is common topology for single quadrant operation. The digital cards are simply provides single quadrant mode PWM for a buck converter driving. Fig. 1 shows the proposed bi-phase type buck converter. The maximum output current is 300 A, so we chosen bi-phase method implement more high current rating capability. IGBT device is twins 400 A Ic for parallel operation. Two independent switches were derived by 180 degrees phase shifted (delay) PWMs which makes them two-phase operation.

The FIR solenoid PS hardware specification is shown in table 1.

Table 1: The Specifications of the FIR solenoid PS

Parameters	Specifications
Output voltage/current	20 V / 200 A
Load resistance	0.1 Ohm
Operating quadrant	1 Q
Stability (0 sec to 60 sec)	± 5 ppm
Stability (> 12 hours)	± 25 ppm
Resolution of output current	> 17 bit
Reproducibility	± 10 ppm
Switching frequency	25 kHz bi-phase

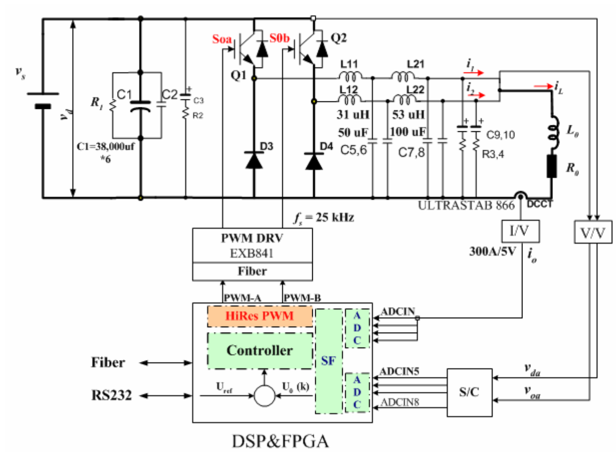

Figure 1: Hardware block diagram of the proposed switched-mode power supply

Controller description

Fig. 2 shows 3U size DSP and AD/DA cards for implementation of digital control power supplies. The core processor is Analog Device SHARC ADSP-21065L 66 MIPS floating-point capabilities with 66 MHz clock. FPGA are used for PWM generation and communication with 5 Mbps fibre channels and 115.2 Kbps serial as well

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as 16 digital inputs and 8 digital outputs. For the accelerator control system, 5 Mbaud are applied with VME SBS for fast global control system. In addition to service mode support RS232 serial that is easily used for testing and diagnostics. DSP internal tasks are running every 20 μs (@ 25 kHz PWM frequency) for regulation of loops which perform calculation of error compensation and communication with AD/DA cards.

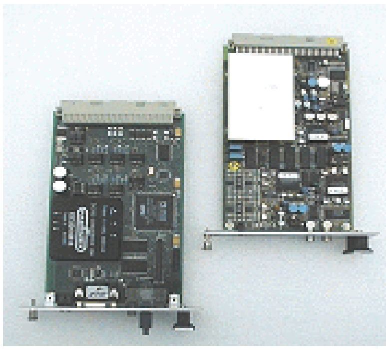


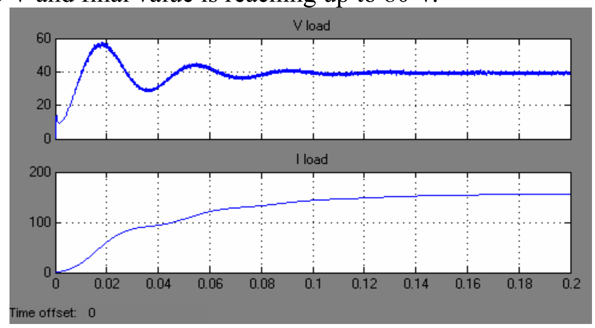
Figure 2: Digital control cards from DLS.

Left: DSP card, right: ADC card

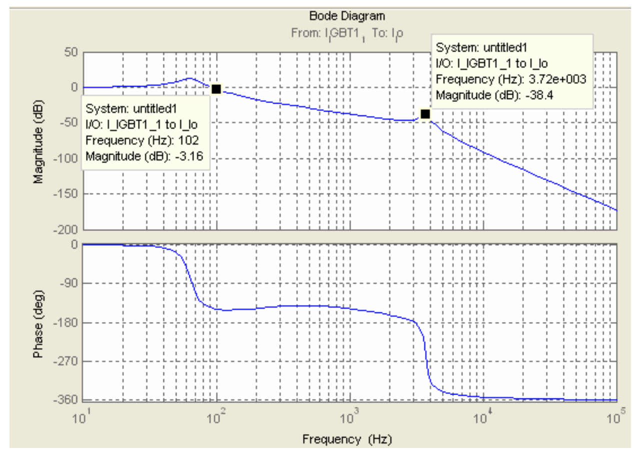
Hardware Circuit Model

Matlab/simPowerSystem is widely using a power electronic circuit simulation. Fig. 3 shows the simplified model of Matlab/simulink for buck converter hardware characteristics of open-loop simulation. Voltage source is VCS (Voltage Controlled Source) DC 20V to 80 V step signals. Input LC and damping RC for DC-link voltage soothing filter the cut-off frequency is near to 45.6 Hz (L = 2 mH, C = 10 mF). Switch model is IGBTs and switching frequency is 25 kHz. In order to simulation buck-converter a power supply with the fallowing values were selected; L1 = 31 μH, L2 = 53 μH, C1 = 50 μF, C2 = 100 μF and magnet load is 10 mH 0.1 Ohm. Switching frequency is 25 kHz with filter order is 5^{th}. Output filter cut-off frequency is the 100 Hz, It given by Fig. 4 (b).

Fig. 4 shows simulation result of load response and filter Bode plots by Fig 3. The output result waveforms are averaged continuance model. Output voltage oscillations are induced from Vin step transient. Input initial voltage is 20 V and final value is reaching up to 80 V.



(a) Output voltage and current time constant



(b) Output filter Bode plots. Cut-off frequency: 100 Hz

Figure 4: Simulation result

EXPERIMENTAL RESULTS

Fig. 5 photograph shows a prototype was built and investigates for FIR solenoid PS. It housed 19" standard rack and divided into three parts; transformer, power stack, and output filter module. Experimental points are focused parallel mode IGBT operation, current stability and

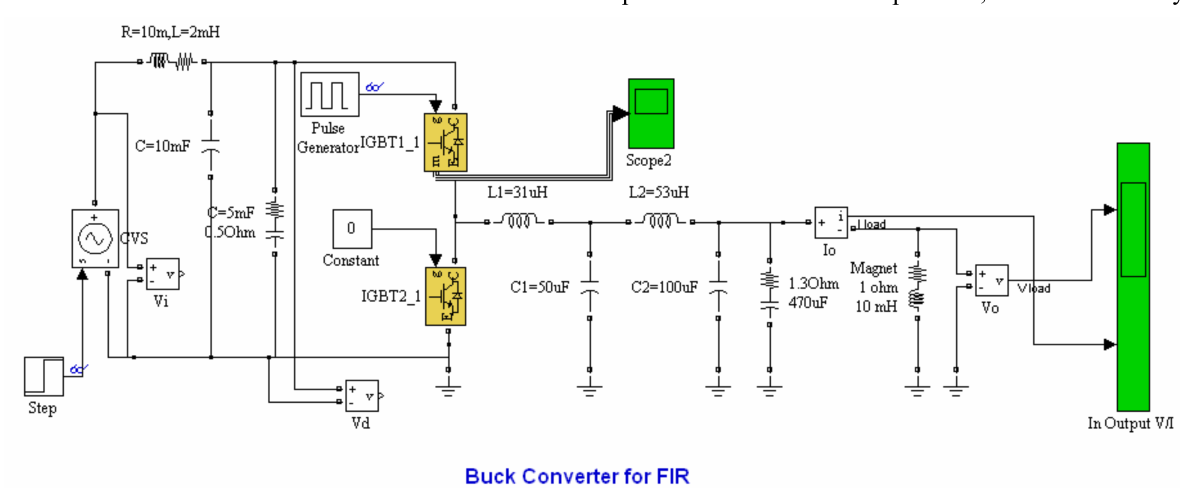


Figure 3: The simulink scheme of the buck converter model

current ripple.

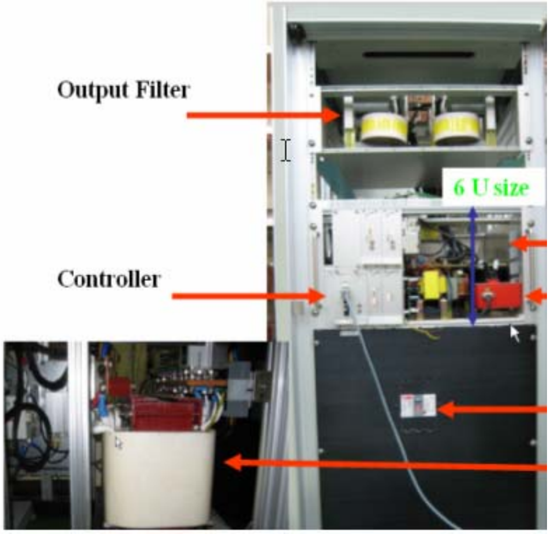


Figure 5: Photograph of completed PS

Fig. 6 shows the PWM signals for IGBTs gate drive and output current ripple waveforms. The PWM 1 and PWM 2 was 180 degree phase delayed due to the one periodic switching. The summing output current ripple is 50 kHz frequency.

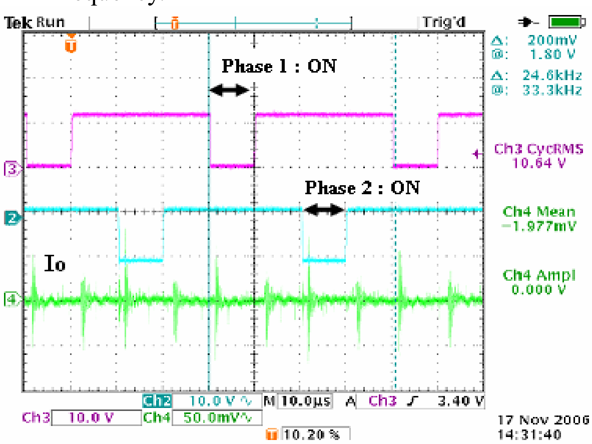


Figure 6: Experimental result of the PWM and current ripple waveform @ 150 A / 20 V. Up: Phase-1 PWM (10 V / div), Middle: Phase-2 (10 V / div), Bottom: Current ripple (50 mV / div), Horizontal time: 10 µs

Fig. 7 shows experimental result of output 5th order filter frequency characteristics. The SR780 Stanford Research Network Signal Analyser is used for the measurement. In the first, filter input have white source from instrument after measurement the response and secondly measurement with variable current 10 to 260 A. The practically attenuation is -70 dBVrms above the 1 kHz; the rejection value is -80 dBVrms at the switching frequency.

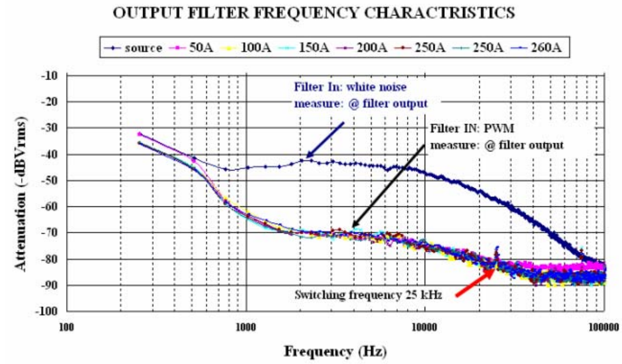


Figure 7: Experimental frequency response of the output LC filter. Upper trace: White source input, Lower trace: real current, horizontal scale is 100 Hz to 100 kHz; Vertical scale is -100 dBVrms to -10 dBVrms

Fig. 8 shows the one hour output current stability at 100 A. It means 3 ppm was very stable current regulation performance due to one hour.

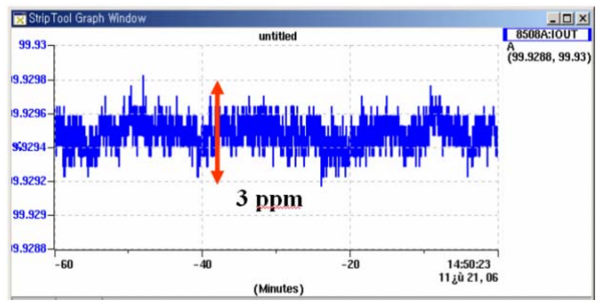


Figure 8: Current stability due to one hour

CONCLUSION

High precision bi-phase digital buck converter was successfully developed for PLS FIR solenoid. By the combination PSI digital cards an extremely flexible and fast prototype produced.

The current stability of the power supply is ± 25 ppm, the current reproducibility is ± 10 ppm and the current ripple is ± 100 ppm. Only single control loops are working well for two legs IGBT parallel operation.

This PS will be installed to the FIR machine by the Feb 2007.

ACKNOWLEDGEMENT

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